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BUBBLE EFFECTS AT RHIC/LHC**

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Searching for Quark-Gluon Plasma (QGP) Bubble Effects at RHIC/LHC

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Abstract

Since the early eighties, we have shared with Leon Van Hove the view that if a QGP were produced in high energy heavy ion colliders that its hadronization products would likely come from small localized in phase space bubbles of plasma. In previous papers we have discussed the case where one to at most a few separated bubbles were produced. In this paper we develop a model based on HIJING to which we added a ring of adjoining multi bubble production, which we believe is a higher cross-section process which dominates the near central rapidity region .

We have performed simulations which were designed to be tested by the expected first to become available suitable test data, namely the forthcoming RHIC STAR detector data on 65 GeV/n *Au* colliding with 65 GeV/n *Au*. We took into account background effects and resonance effects so that a direct comparison with the data, and detailed test of these ideas could be made in the near future. Subsequently 100 GeV/n *Au* on 100 GeV/n *Au* forthcoming data can be tested, and of course these techniques, suitably modified by experience can be applied to it and eventually to LHC.

We concluded that two charged particle correlations versus the azimuthal angle $\Delta\phi$; vs the opening angle, and vs pseudorapidity η , can detect important bubble signals in the expected background, with statistical significances of $5 - 20\sigma$, provided the reasonably conservative assumptions we have made for bubble production occur.

We also predicted charge fluctuation suppressions which increase with the bubble signal, and range from $\sim 5\%$ to 27% in the simulations performed. We demonstrated reasonably that in our model, these charge suppression effects would not significantly be affected by resonances.

We await the forthcoming data to test these ideas.

1 Introduction

If QCD is correct there is no doubt that under conditions that exist in LGT calculations a large volume quark-gluon plasma (QGP) should be creatable. However a poignant question which occurs is, can high energy heavy ion collisions such as (65-100) GeV/n *Au* colliding with a (65-100) GeV/n *Au* in the RHIC collider reproduce the LGT calculational conditions well enough, to produce a large volume of QGP with sufficient cross-section to be detected experimentally. This has more or less been assumed in many theoretical calculations, but to our knowledge no-one has shown that the actual dynamical conditions existing at RHIC

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would allow this to occur at detectable cross-sections or even with effectively non zero cross-sections. The passage of two Lorentz contracted heavy ions through each other in the short times available, under the turbulent ever changing dynamical conditions of the environment resulting from their interaction, does not give one assurance that even the very basic requirements of thermal and chemical equilibrium required can be met. Certainly this has not been demonstrated by any theoretical work we are aware of. Therefore from the early eighties onward, as documented in the first four RHIC experimental workshops from 85-90[1] we have concluded this is not likely to happen. Instead we felt that if QGP is created in a collider such as RHIC or LHC, it is more probable that local fluctuations would produce one too many droplets (clusters, chunks or bubbles) of QGP which would possibly be detectable, especially if they were localized in phase space. Leon van Hove had this view and did string model calculations[2, 3] which resulted in small droplets of QGP being formed by the breaking of stretched strings. These QGP bubbles were localized in rapidity and gave rise to rapidity bumps or peaks in the rapidity or pseudorapidity distribution.

We have previously published[4] a treatment of the single (spherical-no longitudinal expansion) bubble case (similar to the Van Hove type) and it serves as an introductory paper for the general subject. Although it is possible that with enough statistics one could in principle find single to a few bubble events, we have felt that multi bubble formation (which we mentioned but did not do calculations for in ref[4] is the more probable general case which should be treated for realistic attainable statistics. Of course a large number of bubbles in the multi bubble case will obscure the resolveability and observation of single bubble phenomena such as rapidity bumps etc. Furthermore the overall result would likely appear similar to a thermal model. However this likely occurs because particles from different parts of space go into the same phase space. If all of the bubbles were Van Hove spherical bubbles and at rest (i.e. located at mid rapidity), even though they are at different space points, they would add up to be equivalent to one big Van Hove spherical bubble. If we now give motion to each bubble along the beam direction they will smear out in momentum space. Therefore to practically detect the effects of the multi bubble case, we must carefully choose a region where phase space focusing will allow the addition of multi bubble effects to add in a way which gives a detectable signal. In other words we must find a part of momentum space that is highly correlated to position space. If we could force bubbles to remain at rest then their particles would add together forming a rapidity bump at $\eta = 0$. Even if this happened it would be difficult to get a clean signal over background in this region, because background particles from soft fragmentation end up at central rapidity. Thus it is important to find a phase space region free of such background.

It turns out that at RHIC the prehadronic matter is being pushed in the transverse direction[5] building up transverse momentum p_t . Bubbles that are pushed along with this flow will hadronize into particles which will be focused over a limited range of angles. Thus in this paper we will model such bubbles and address backgrounds which mimic bubble effects-which turn out to be mainly jets and to some extent resonances.

The above states the goals of this paper. We will treat the case of an approximately maximum number of multi bubbles in one outer ring around the blast region, contributing to the final hadronization of particles coming from the QGP. Although this may not occur

in the actual case-only a future data analysis, can shed light on this. We will find that a reasonable theoretical treatment can lead to methods for detecting QGP bubbles.

In this paper we are essentially limiting ourselves to simulations and analysis suitable for comparison with RHIC forthcoming data, since a considerable body of data has already been published, and it is expected that in the near future forthcoming data from RHIC for 65Gev/n *Au* colliding with 65 GeV/n *Au* could test these ideas. However similar methods could be applied later to higher energies at RHIC and LHC.

2 General Considerations

At RHIC the prehadronic matter is being pushed in the transverse direction[5]. Particles with higher transverse momentum (p_t) are pushed more than particles with lower p_t . Pion HBT[6] has shown that at low p_t the source size is about $6f$, while above 0.8 GeV/c the source size becomes about $2f$ allowing phase space focussing to form a signal. These measurements imply that the viewed region of the initial position space becomes smaller as one selects higher p_t particles. Pions at a $p_t \sim 1\text{-}2$ GeV/c will be coming from the outer regions of the expanding fireball. This outer radial region will have a radial width of the order of $2f$, while the interior region where the softer pions come from will mainly have a radius of about $6f$. This supports a rough estimate of $\sim 6+2 \sim 8f$ to be the transverse radius of the fireball that is emitting particles. One should keep in mind that this is a quantum mechanical system with dynamical and turbulent changes, therefore the previous arithmetic, and subsequent arithmetic is to be considered in the sense of very crude estimates. One should note that particles above 2 GeV/c will likely have jets as a sizeable source of contamination. Thus we believe we can work with a window with p_t of (0.8 to 2) GeV/c to search for multi bubble effects. We chose the upper end of the window to avoid the hard physics region above 2 GeV/c, which would increase the background for the effects we are looking for. The lower end of the range is chosen to maintain the space momentum correlation of our signals, and therefore enhance them.

From Ref.[4] we found that the single plasma bubbles have a mean p_t of about 0.5 GeV/c. Thus the angular range in $\Delta\phi$ can be crudely estimated for the bubbles in our window. With an average p_t of about 1 GeV/c and the above right angle momentum we form ~ 30 degree angle and thus we can assume an approximation that spherical bubbles have an angular range in $\Delta\phi$ of about 30 degrees. This however is very similar to the angular spread of jet fragmentation, making it very difficult to separate spherical bubbles $\Delta\phi$ distribution from the $\Delta\phi$ distribution of jet fragmentation. However it might be noted that there are arguments for jet quenching[7] which would improve our signal. However we will ignore them in our simulations in order to be very conservative in drawing our conclusions. We know that there is a longitudinal expansion-the Landau fireball effect. The value of this longitudinal expansion has to be determined from analyzing the data. However the Landau bubbles longitudinal expansion used in our previous paper[4] was probably too large, so we will choose a reasonable value intermediate between that and the value for a spherical bubble (which has zero longitudinal expansion) for the simulations in the present work. In the language of

Van Hove, the string stopping after breaking is not complete, so that longitudinal expansion is left in the strings or bubbles. The longitudinal expansion will increase the angular spread of $\Delta\eta$ due to bubbles, which will distinguish bubbles from jet fragmentation. However it will spread out the bubble signal, but this may not matter. Increasing the energy in the bubble (which reasonably could occur) would enhance the bubble signal. This leads to our using an about 50° range for the bubbles in the psuedo-rapidity direction for our simulations. The angular range of the bubbles in the azimuthal direction is about 30° , as previously discussed. From HBT work previously referred to, we can estimate the bubble would have a radius of about $2f$, and thus has a diameter of about $4f$. The rapid transverse expansion in the blast region pushes high density prehadronic matter from the central regions outward to where it hadronizes[6]. We assume a single outer ring of bubbles at the outer circumference of the blast region at hadronization would be filled with bubbles which provide the hadronization coming from the QGP. Since 30° is one twelfth 360° and each bubble has a diameter of about $4f$, the circumference to cover the entire azimuthal region, would be approximately $48f$. A circumference of $48f$ implies a radius of $8f$ for the ring of bubbles. The number of $8f$ is consistent with our HBT picture presented previously. Inside this outward shell of bubbles one would expect there may be many overlapping bubbles. Using the work in ref.[8] that bubbles of a $2f$ (one of the choices) bubble size for a RHIC event would have about 40 domains (which we call bubbles) with energies of about 3 Gev going into charged pions. We calculated the energy per domain(bubble) using the information in their paper. For our simulations we felt it was reasonable to use the $2f$ bubble size in employing the methods in [8] since it was consistent with the HBT work. We also felt that in this first simulation it was reasonable to use our calculation (based on[8]) of about 3 Gev per bubble hadronizing into charged pions in order to avoid being arbitrary, but obviously this value has to be considered a parameter which could be determined in conjunction with data analysis when it becomes available. However it should be noted we are not using any of the other detailed work in Ref.[8]. We used an average of 13 mid-rapidity bubbles in a ring at mid-rapidity in each central 65 Gev/n *Au* on 65Gev/n *Au* event, since this would fill the ring of bubbles whose contributions would dominate what is seen at central rapidities at the RHIC STAR Detector. This detector would be the most likely near future source of experimental results to check these ideas. We use an average of 3.25 Gev (we increased the energy from 3.0 GeV since we are producing more than pions) going into charged particles, per bubble, and this led to an average of 1.95 charged particles going into the cuts we will use. In our bubble scenario each QGP bubble is an uncharged gluon dominated color singlet system. Thus when the bubble hadronizes the total charge of the particles coming from the bubble is zero. Since we are selecting a p_t range where we expect the bubble concentration to be rich we should therefore see a suppression of charge fluctuations, since the charge fluctuations coming from a localized QGP bubble should be less by a factor ~ 4 than charge fluctuations coming from an ideal pion gas. This subject will be addressed in the next section.

3 Charge Suppression Effects Due to QGP Formation

At this point we can address recent papers on charge fluctuation suppression calculations of the ratio of positively charged and negatively charged pions as a signal for QGP formation. In the letters of S. Jeon, and V. Koch[9], and M. Asakawa, U. Heinz, and B. Mueller[10], they concluded that a parameter $D = \frac{4\langle\Delta Q^2\rangle}{\langle N_{ch}\rangle}$ meson evaluated for event by event charge fluctuations is ~ 4 for an ideal pion gas for mesons coming from non plasma production, whereas it would be approximately 1 for mesons originating from a QGP both from LGT or ideal gas calculations. Correcting for resonance effects in actual observations, they concluded the observed D would become 3-2 respectively. Therefore they argued observing these reduced charge fluctuations would serve as a distinct signal for QGP production. We pointed out[11] that their method of treatment[9, 10] allowed color charge fluctuations which they overlooked. These color charge fluctuations were shown by us to be important, and could modify the result by washing out or even entirely eliminating the charge suppression effects they were predicting[11]. We also pointed out[11] that in their treatments, even if locally in space one has a charge fluctuation suppression of $\sim 70\%$ to 50% , kinematic mixing of position space into momentum space causes electric charge fluctuations to increase, thus reducing suppression and even possibly eliminating the suppression all together. Cuts on the particles one measures will also reduce the calculated suppression. If one gains particles from other parts of position space, that reduces the calculated suppression. Thus we concluded that it is unlikely their arguments could support their predictions for observation of electric charge fluctuation suppression even if large volumes of QGP were produced as they assumed.

4 Electric Charge Fluctuation Suppression in the Bubble Scenario

In our bubble scenario each QGP bubble is a very localized color singlet and uncharged system. Thus when the bubble hadronizes the total charge of the particles coming from the bubble has to be approximately zero, and due to the localization, color charge fluctuations and most of the kinematic mixing effects which can drastically change the suppression predicted in [9, 10], do not occur. Since we are selecting a p_t range where we expect the bubble effects to be substantial, we should see a suppression of charge fluctuations in the charged particles coming from the QGP bubbles. The large predicted reduction by a factor of ~ 4 of charge fluctuations which is reduced to $\sim 2-3$ by resonances in[9, 10], will not be achieved by our measurements because we take account of the presence of background particles and the loss of some of the plasma particles out of our cuts. However there will be predicted a measureable reduction and it might be sizeable. In a study of resonance effects, we will find that conclusions from our simulations for our chosen signals are not significantly affected by resonance background. Thus we expect under the bubble scenario that we are following there will be predicted observable charge suppression, which will be good evidence for QGP formation if observed. One needs to await analysis and availability of the relevant data to test, and if it appears relevant, to optimize these ideas.

5 HIJING Based Model

Our first objective is to construct a model which will hopefully take account of the most important effects due to QGP Bubbles and background and other effects so that a direct comparison of the model predictions and the future RHIC data can be made in a reasonably quantitative manner. We now make a model based on the HIJING event generator[7]. For *Au on Au* at 130 GeV/c per nucleon. HIJING is a good choice to base a simulation on since it has min-jet which is a important source of background for our simulations. Furthermore HIJING has been sucessfully used to fit, and help with the analysis of RHIC data in numerous instances. However HIJING has one important missing part for our *Au on Au* simulation and that is elliptic flow which has been measured at RHIC[12]. Not taking account of elliptic flow would unrealistically modify our simulation results. Therefore we have modified HIJING to include elliptic flow effects. HIJING has two relevant sources of particle production: Jets which fragment into particles which are referred to as jet particles, and the soft particles which come from beam jet fragmentation. The jet particles are not flat in azimuth but bunch around the jet axis. The beam jets fragmentations are very flat in azimuth. To take account of the observed elliptic flow we modify the azimuthal distribution of the soft particles (beam jets) so that we develop a $\cos 2\phi$ component about a fixed axis for each *Au on Au* simulated event. Into each central *Au on Au* event we add on the average 13 adjoining bubbles in a single ring in the central rapidity region as discussed previously. Each bubble contributes from 1 to 4 charged particles to the η range of $+0.75$ to -0.75 , with p_t greater than 0.8 GeV/c and less than 2.0 GeV/c. This p_t cut has its lower bound chosen to maintain the space momentum correlation which enhances our signal, while the upper bound is chosen to avoid contamination from the hard physics region above 2 GeV/c, and it is our most relevant p_t cut. However some of the time we use 1.2 GeV/c for the lower bound to investigate and separte various effects as indicated on some figures and in the text. The total charge of each bubble was set to zero, which is appropriate for a QGP bubble. We then generated 100,000 bubble events with impact parameter ranging from 0.0 to 4.0. We also generated 100,000 events of our modified HIJING (taking into account relevant elliptic flow effects).

In figure 1 we show the $\Delta\phi$ correlation generated by the above simulations which have the addition of the bubble effects to our modified HIJING which has relevant elliptic flow effects included. For comparison we make use of our modified HIJING which has the beam jets modified by elliptic flow and the expected mini-jets predicted by HIJING. For *Au on Au* for a total of 130 GeV/c per nucleon- nucleon collision and the standard 2 GeV/c QCD cutoff, one obtains an average of 17.6 jets per event from which 13.3 charged particles fall into our cuts (Fig. 1). Since it appears the STAR detector at RHIC is the best bet for experimentally checking in detail the theoretical calculations in this paper, we have added two track merging that one sees in the STAR detector[6]. This inefficiency only effects small $\Delta\phi$'s. In figure 1, we see that the plasma bubbles have a stronger correlation than the standard mini-jets. In order to make quantitative comparisons for angles less than 60° where we expect the bubbles to contribute, we calculate χ^2 in all angular correlation calculations with this cut. In figure 1 the χ^2 is 53 for 8 bins (Degrees of Freedom). This a $\sim 8\sigma$ effect. However since the theory predicting the number of mini-jets is not exact, and we wish to be conservative, we ask the question, by how much of a factor do we have to increase the

HIJING predicted jets to make the bubble effect difference in $\Delta\phi$ become indistinguishable from HIJING with the added jets. In figure 2 we show that from an 100,000 event simulation, that arbitrarily doubling the number of mini-jets in HIJING causes the chisq to drop to 6 resulting in no difference between bubbles and arbitrarily increasing the number of mini-jets generated by HIJING to double. This represents a very conservative, and probably an excessively overdone approach, especially since reasonable arguments exist that actually jet quenching rather than enhancement occurs[7]. The agreement between HIJING plus bubbles and HIJING plus double jets is also good if we choose a tighter cut with a p_t range 1.2 to 2.0 GeV/c (see Fig. 3; $\chi^2 = 10$). If we bin in $\Delta\eta$ and plot HIJING plus bubbles and HIJING plus double jets we see the correlation for the bubbles compared to the jets in Figs. 4-7 for various $\Delta\eta$ ranges. The χ^2 for the 4 figures are 1, 4, 14, 1 for 3DF. Only figure 6, shows a difference, with some statistical significance of over 3σ for particles which are separated by $\Delta\eta$ of 1.05. The difference is that the correlation is wider for the bubbles compared to the jets. This difference in width along the η direction, is expected from the Landau bubbles which have longitudinal expansion. With more statistics in the simulation we could expect that the differences in width along the η direction would become more evident and have better statistical significance due to the nature of the effects longitudinal expansion produces. Let us look at an angular correlation of the angle between particles (opening angle $\cos\Theta$). Figure 8 indicates that the bubbles have a wider correlation than the double jets. The χ^2 for Fig. 8 is 26 for 8 DF which is also $\sim 3\sigma$. Next let us do $\Delta\phi$ correlations for like and unlike charges separately. In figure 9, we show this correlation for the p_t range 0.8 to 2.0 GeV/c. We see that the difference between the unlike and like charges $\Delta\phi$ correlation is larger for the bubbles than for double jets. The χ^2 is 70 for DF=24 ($3 \times 8 = 24$) which is a 5σ effect. This difference is due to the zero charge of the bubbles while jets only have a reduced charge. This represents the charge fluctuation suppression effects we are looking for. We can form a measure of charge fluctuations by looking at the charge difference event by event for particles which lie in our p_t range (0.8 to 2.0 GeV/c) and η range ($|\eta| < 0.75$). For the mean of the charge difference with our average of 108 particles per event we get 4.0 positive charges per event. The width for the double jets is 10.4 particles. The square root of 108 is 10.4. Thus the width for the double jets is consistent with purely random. The width for the bubbles is 9.7 particles thus being consistent with 95% of random. When pairs of charges are created and go into the p_t window (0.8 to 2.0 GeV/c) then the charge fluctuations are reduced. However when one charge goes into the window and one outside there is a pure random addition. Since we see a net positive charge there must be baryon transport to the central region. We are summing over impact parameters of 0.0 to 4.0 f and thus have a varying fluctuation of baryon transport. For more central events the net positive charge must be bigger and for the less central events this positive charge must be smaller. This effect causes a larger than random fluctuation. It also appears that they cancel out for our HIJING simulation with the double jets. The bubble fluctuations appear some what smaller. This is because not all the bubble is contained in the above cuts. Pions from the bubble endup having p_t near the lower edge of the p_t range. The kaons are boosted to the midrange and protons are near the upper range. As stated previously. The upper end of the range is chosen to avoid the hard physics region above 2.0 GeV/c and the lower end of the range is chosen to maintain the space momentum correlation. It should be noted when in the future the planned Time of flight system which surrounds the central TPC at RHIC

becomes available, we will be able to do much more detailed treatments similar to the above for π^+ and π^- , K^+ and K^- , and p and \bar{p} instead of just using, all positive and all negative charge pairs. When eventually there is enough experimental statistics available to compare with we can do multi particle correlations for larger numbers of particles.

6 Estimating Resonance Effects with a Resonance Gas Model

In order to estimate resonance effects, we use a model based on simple thermal ideas plus resonances expected in a hot hadronic system. For thermal particle production we will use a simple factorized form for p_t and y of our particles and resonances.

$$\frac{d^2 N}{dp_t dy} = A p_t e^{-\frac{M_t}{T_e}} e^{-\frac{y^2}{2s^2 y}}. \quad (1)$$

The inputs are the mass of the particle (m) and the thermal temperature of the particle (T_e) and the Gaussian width in rapidity σ . The resonance mass is smeared by a Breit-Wigner form. A typical resonance is the K^* which has a form:

$$\begin{aligned} W(M) &= \frac{\Gamma_{(q)}^2 M_{k^*}^2}{(M^2 - M_{k^*}^2)^2 + \Gamma_{(q)}^2 M_{k^*}^2} \\ \Gamma(q) &= \frac{2\Gamma_{k^*}(q/q_0)^3}{1 + (q/q_0)^2}. \end{aligned} \quad (2)$$

where M^* is the mass of the K^* and $\Gamma_{(q)}$ is the total width and q is πK C.M. momentum and q_0 is the saturation momentum. The power 3 and 2 is $2l + 1$ and $2l$, where l is the angular momentum of the πK system. We also need to add elliptic flow[12] to our particle production. A very simple p_t dependent V_2 parameter is used for our resonance gas as we used for the beam jets in HIJING. We used the form

$$E \frac{d^3 N}{dp^3} = \frac{1}{2\pi p_t} \frac{d^2 N}{dp_t dy} [1 + 2V_2 p_t \cos 2(\phi - \Phi_R)] \quad (3)$$

Table I				
particle	number	temp	width	V_2
π^+	115	.250	3.00	.12
π^-	115	.250	3.00	.12
ρ^0	350	.290	2.90	.12
ω	252	.290	2.90	.12
η	505	.290	2.90	.12
k^+	133	.260	2.20	.09
k^-	116	.260	2.20	.09
k_s	125	.260	2.20	.09
k^{*+}	19	.260	2.20	.06
k^{*-}	17	.260	2.20	.06
k^{*0}	35	.260	2.20	.06
p	45	.320	1.80	.03
\bar{p}	33	.320	1.80	.03
Λ	71	.360	1.80	.03
$\bar{\Lambda}$	50	.360	1.80	.03
Σ^+	33	.360	1.80	.03
Σ^-	33	.360	1.80	.03
$\bar{\Sigma}^+$	21	.360	1.80	.03
$\bar{\Sigma}^-$	21	.360	1.80	.03
Ξ^0	17	.330	1.80	.03
Ξ^-	17	.330	1.80	.03
$\bar{\Xi}^0$	13	.330	1.80	.03
$\bar{\Xi}^+$	13	.330	1.80	.03
Ω^-	4	.300	1.80	.03
Ω^+	4	.300	1.80	.03

Here there is only one parameter which is V_2 . We can also add min-jets from HIJING[7] as we did above. In Refs.[9-11] one expects a thermal resonance gas system should have a suppression of charge fluctuation of the order of 20% (if D is ~ 3 due to resonance effects whereas it would be ~ 4 without resonance effects). Using the resonance to pion ratio of Ref.[13] we can generate central Au on Au events at 130 GeV/c per nucleon that are very close to the HIJING simulation using a Boltzman temperature 180 GeV and a Gaussian width rapidity of 2 units. Then for a pseudo-rapidity of $-0.75 < \eta < 0.75$, we can look at the distribution of net charge. From this net charge distribution we can determine the charge suppression. Keeping the final yield of particles the same we increase the resonances until we achieve a 20% reduction in charge fluctuation which represents the resonance effect used in [9-11], and is roughly consistent with observations. The net charge mean is 9.5 with a width of 20. For a random system the width should be 25. Adding jets from HIJING to our Resonance gas does not appreciably change the above results. In table 1, we give the number of particles and resonances used and the temperatures and rapidity widths for each plus the V_2 parameter. Figure 10 shows the $\Delta\phi$ comparison with resonance plus jets to HIJING plus bubbles. We have a χ^2 of 22 for 8 DF which is a $\sim 2.5\sigma$ difference, and thus the two are

statistically equivalent to being the same since we consider at least 3σ required for minimal statistical significance. In Fig. [11] we make a p_t cut ($1.2 < p_t < 2.0\text{GeV}/c$) and see that HIJING plus bubbles has a considerably increased correlation as a function of $\Delta\phi$ in our usual $0\text{-}60^\circ$ cut region. The difference is a χ^2 of 206 which is over 20σ . We see that resonances do not decay most of the time into particles with near enough p_t values to satisfy this cut. Thus by making a tighter p_t cut the correlation in $\Delta\phi$ due to resonances is greatly reduced, and we can use this tightening of cuts to reveal the correlation in $\Delta\phi$ without significant contributions from resonance effects. We now can make a charge fluctuation analysis of the two models inside our standard cuts. The results for resonance plus jets is a 1% reduction in the width of the net charge (10.05 compared to 10.15), whereas for HIJING plus bubbles we see a reduction of 5% in the width (9.73 compared to 10.29).

7 Simulation of Bubbles with 3 Times the Energy per Bubble

Up to this point in our model building, we have calculated the energy in a bubble using the work in Ref. [8] and replacing one of their domains with a bubble of about $2f$ radius which is one of their choices they mention. Our reason for selecting a two fermi bubble is based on using the previously mentioned HBT work on source size and adapting it to our bubble scenario. That seems some what reasonable as a starting point, in order to avoid a arbitrary selection by us. However, one has to admit that the energy per bubble is really a parameter and that their value could be off by a considerable factor. If our use of calculated energy per bubble based on Ref. [8] estimates is too large, we feel it would become increasingly difficult as the energy per bubble decreased to observe multi-bubbles effects using the methods explored above. With the present knowledge of heavy ion data, the uncertainties in using numbers calculated from Ref. [8], and the turbulent fluctuation phenomena which exist, it is reasonable to speculate what would happen if the bubble energies were bigger. Therefore we have rerun our bubble simulation using 3 times the energy per bubble that was used originally. Figure 12 shows the $\Delta\phi$ correlation with the bigger energy bubbles compared to the regular modified HIJING and jets of Fig. [1]. This is a very large effect with a χ^2 of 1840, which is well over 20σ . Next we show the unlike and like sign comparison in Fig. [13]. Here the χ^2 is 4399 thus we see again a very large difference well over 20σ between like and unlike charge pairs. If we look at the charge difference distribution of the 3 times bubble simulation, we find a mean of 4 with a width of 7.6. A pure random case has a width of 10.4 thus leading to about a 27% reduction of charge fluctuation, with $3/4$ of the particles in our cuts come from the plasma bubbles.

8 Most Extreme Pure Neutral Resonance Case

Finally let us explore the most extreme totally unjustified case which should give a maximum charge suppression by generating by a pure neutral resonance system. This possibility has

never been seen in heavy ion collisions and violates isospin symmetry along with other reasonable considerations. We generated this case merely in order to demonstrate that our bubbles focus much more of their decay particles into the cuts than a resonance case can. We will consider charged particles generated by only resonance decay into the region of our standard cuts ($0.8 < p_t < 2.0$; $-0.75 < \eta < 0.75$). For our neutral resonances we will use the ρ and the σ meson. The ρ is given by the $I = 1$, P -wave $\pi\pi$ phase shifts, while the σ is given by the $I = 0$, S -wave $\pi\pi$ phase shift (see Ref.[14]). In the heavy ion final state, we expect many resonances will be formed by pions rescattering in the final state. Therefore the σ meson will have a mass shift due to rescattering like the a_1 meson does in diffractive production[15]. The effective mass spectrum for the ρ and the σ is shown in Fig. [14]. In Fig. [15] we show the $\Delta\phi$ correlation that we have generated using our two resonances. The values used are shown in Table 2. This time we compare our neutral resonance system with the resonance gas system plus bubbles. The χ^2 for these two in Fig. [15] is 11 which is within $\sim 0.5\sigma$ the same. We have compared this extreme pure case to our regular bubbles where $\frac{1}{4}$ of the particles come from the bubble, while 100% of the particles come from the neutral resonances. However again if we make a narrower p_t cut ($1.2 < p_t < 2.0$) the bubble correlation is larger by a χ^2 of 36 which is a 5σ effect (Fig.[16]). Also the width in η is different than that of the bubbles, which can be seen by looking at the opening angle correlation (Fig.[17] which should be compared to Fig. [8]). The χ^2 in Fig. [17] is 50 which is a 7σ effect. The reduction of charge fluctuation for the pure neutral resonance system is an interesting result. This system has a net charge of zero and would have no charge fluctuation if there were no decays, ends up with only a 6% reduced fluctuation in our case. The cause of this effect is decay particles leaking out of the cuts. This 6% is the total amount possible from neutral resonances decaying into our cuts even in this extreme unrealistic case, while if we increase our bubble by 3 times we achieve a 27% reduction in fluctuations. For the resonance gas plus bubbles case which we use in Figs. [15-17], we find has a 7% reduction of charge fluctuations. This is a greater reduction than a pure neutral resonance case. In our bubble model the decay particles are well contained and focused into our cut region.

Thus considering the foregoing analyses, we conclude that background resonance effects will not to any significant degree affect our conclusions based on our simulations.

Table II				
particle	number	temp	width	V_2
σ	69	.700	1.80	.04
ρ^0	20	.700	1.80	.04
σ	1246	.335	1.80	.07
ρ^0	380	.335	1.80	.08

9 Summary and Conclusions

From the early days of QGP theories as documented in the first four RHIC experimental workshops we have shared[1] the viewpoint of Leon Van Hove[2, 3] that localized in phase space bubbles of QGP are more likely to be the origin of the hadronization products which

originate from QGP production if it is produced at high energy heavy ion colliders such as RHIC and LHC.

In a previous publication[4] we have considered the case of one to at most a few separated QGP bubbles being produced, and this could conceivably occur and be observed with sufficient statistics. However although we referred to multi-bubble energy formation in Ref. [4] which we believe is the most likely high cross-section case, we did not calculate that case in Ref. [4]. In this paper we conservatively calculated the multi bubble case, embedded in HIJING, suitably modified for relevant elliptic flow effects, and considered resonance effects. We demonstrated that resonance effects will not significantly affect our conclusions. Since the first test of our ideas will come from forthcoming STAR data at RHIC, we made every reasonable effort to cast our predictions in a form which could be directly and quantitatively compared with the forthcoming STAR data for 65Gev/n *Au* colliding with 65 GeV/n *Au*. Obviously the methods and models we used could also (suitably modified in the light of experimental results) be used for higher energy RHIC data, and eventually for LHC data. It is expected that high statistics data on 100Gev/n *Au* colliding with 100 GeV/n *Au* will subsequently become available in the near future and allow a more critical comparison with these ideas. We used a $2f$ radius bubble size based on HBT work[6] which shows that above p_t of 0.8 GeV/c the source size has a radius of about $2f$ and is consistent with a $2f$ bubble size in Ref. [8] (one of the choices). We showed that a reasonable estimate of the outer shell of a ring of adjoining bubbles around the blast region, at central rapidity, when hadronization takes place is located at a radius of about $8f$, and the width of this outer shell is roughly $\pm 2f$ about the $8f$ radius. We added a reasonable estimate of longitudinal expansion to the bubbles in order to take account of the expected Landau effect, but comparisons with the data can determine this value. The lower bound in p_t is chosen to maintain the space momentum correlation corresponding to the $2f$ source size, which is consistent with the HBT work and enhances our signal. The upper bound in p_t is chosen to avoid the contamination from the hard physics region above 2 GeV/c. However at times we also raised the lower bound of the p_t cut to 1.2 GeV/c for various reasons as explained in the text. Since we estimated the ϕ angular range to which each bubble contributes is about 30° , we used an average of 13 adjoining bubbles around a ring in the central rapidity region to fill the ϕ coverage. Our standard cut in η was -0.75 to $+0.75$ to cover the central region dominated by our bubble ring hadronization products. Each bubble is considered to be a localized gluon dominated uncharged color singlet system. Thus when the bubble hadronizes the total charge coming from the bubble was set equal to zero. Our demonstrated by simulations important signals for the QGP bubbles which had a statistical significance of 5σ or more included:

- The angular correlation of charged particles as a function of ϕ and also opening angles in the 0-60deg range where our bubbles contribute.
- Predicted suppression of electric-charge fluctuations.

Some of our significant results are:

For Correlation vs $\Delta\phi$: Fig 1 compares modified HIJET and modified HIJET with the addition of bubbles which results in an 8σ difference effect (see text) for our 0-60deg cut

where the effect of bubbles is expected to occur. This cut is used on all angular distributions. To remove this difference requires the very conservative extreme measure of doubling the number of jets (as shown in Fig. 2 and text) when there are arguments that jet quenching occurs rather than enhancement. In Fig. 9 we see that when we compare the $\Delta\phi$ correlations for like and unlike charge particles there is a 5σ difference in the case of the bubbles plus modified HIJING plus double jets. This is caused by charge suppression due to bubbles.

We pointed out[11] that earlier work[9, 10] on charge fluctuation suppression overlooked color charge effects, and kinematic mixing effects which could drastically reduce or even more or less eliminate the calculated suppression. In our localized bubble scenario these effects cannot occur. In our analysis the predicted observed charge suppression in the 65Gev/n *Au* on *Au* simulations will range from about 5% for the Ref. [8] based value of about 3.25 Gev per bubble going into charged particles to about 27% for about 10 Gev per bubble going into charged particles. In the case of 10 Gev per bubble going into charged particles, we find the difference in the $\Delta\phi$ correlation between our modified HIJING in Fig. 1 and modified HIJING plus bubbles is huge (see Fig. 16 and text), and well over 20σ . Also in Fig. 17 using the same modified HIJING plus bubbles model the difference in the $\Delta\phi$ correlation between like and unlike charge correlations is huge and well over 20σ .

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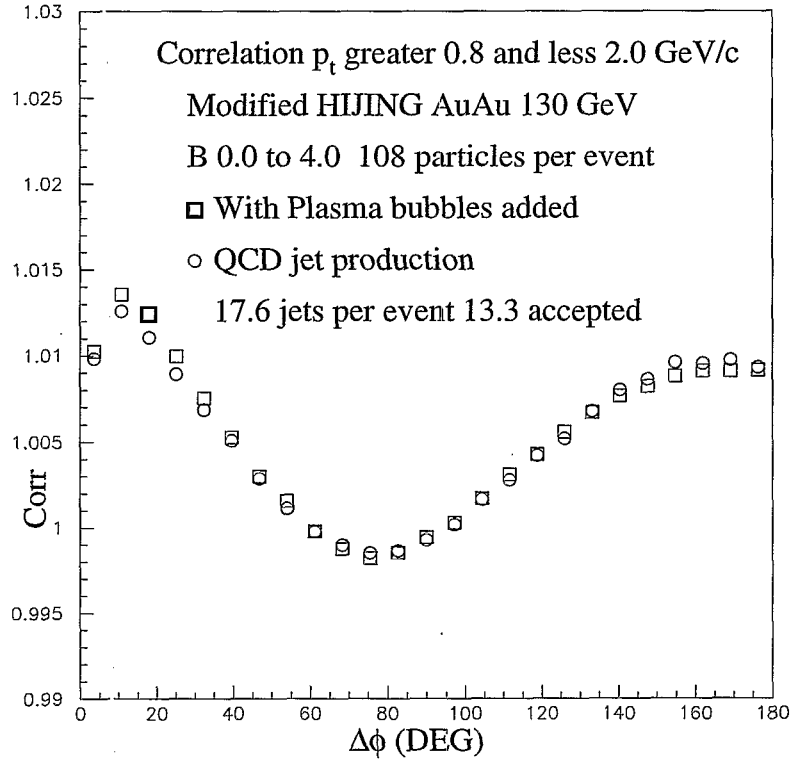


Figure 1: The $\Delta\phi$ correlation of charged particles which lie between p_t (transverse momentum) 0.8 to 2.0 GeV/c for two different models based on HIJING (see text). The circles are HIJING (with elliptic flow) plus jets and the squares are HIJING (with elliptic flow) plus plasma bubbles (see text). Also absolute η (pseudorapidity) < 0.75 is required.

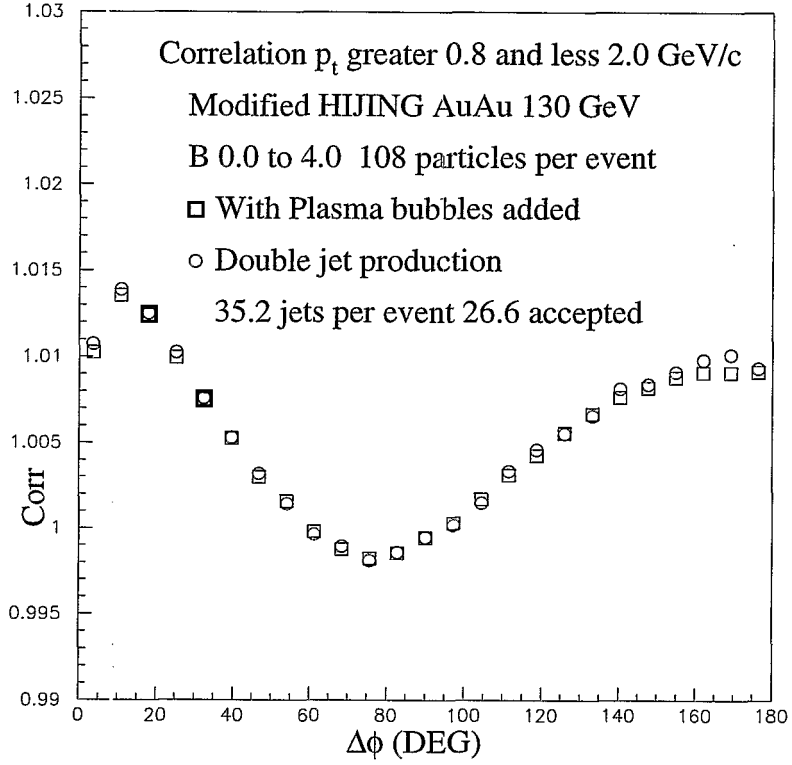


Figure 2: The $\Delta\phi$ correlation of charged particles ($0.8 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) for two different models based on HIJING. The circles are HIJING plus double the number of expected jets and the squares are HIJING plus plasma bubbles. In calculating χ^2 values for differences (in text) the data in every figure were always cut for an angular range from 0 to 60 degrees since that is where we expect the bubble effects to occur.

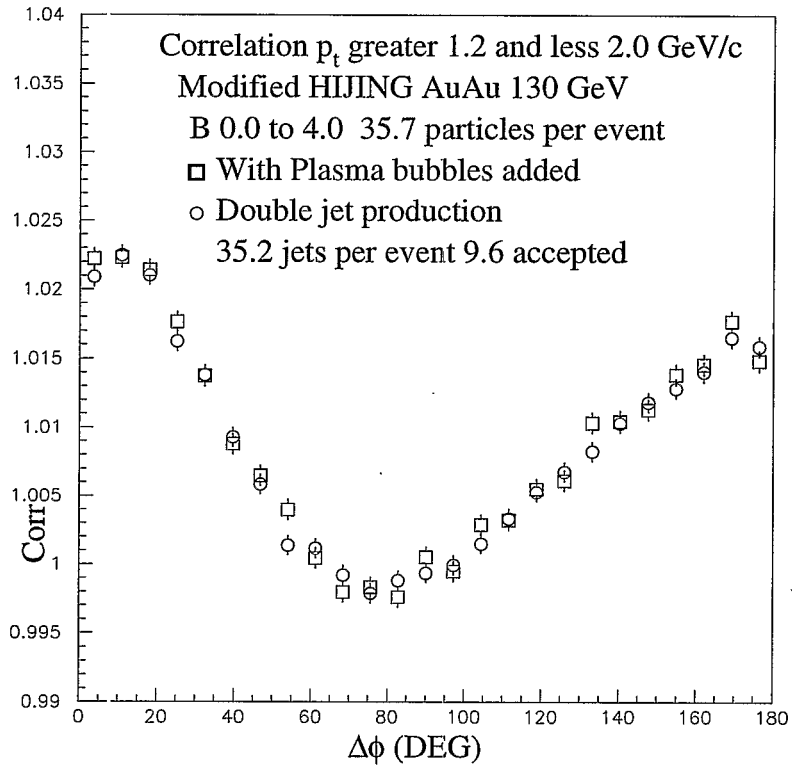


Figure 3: The $\Delta\phi$ correlation of charged particles ($1.2 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) for the same models as Fig.[2].

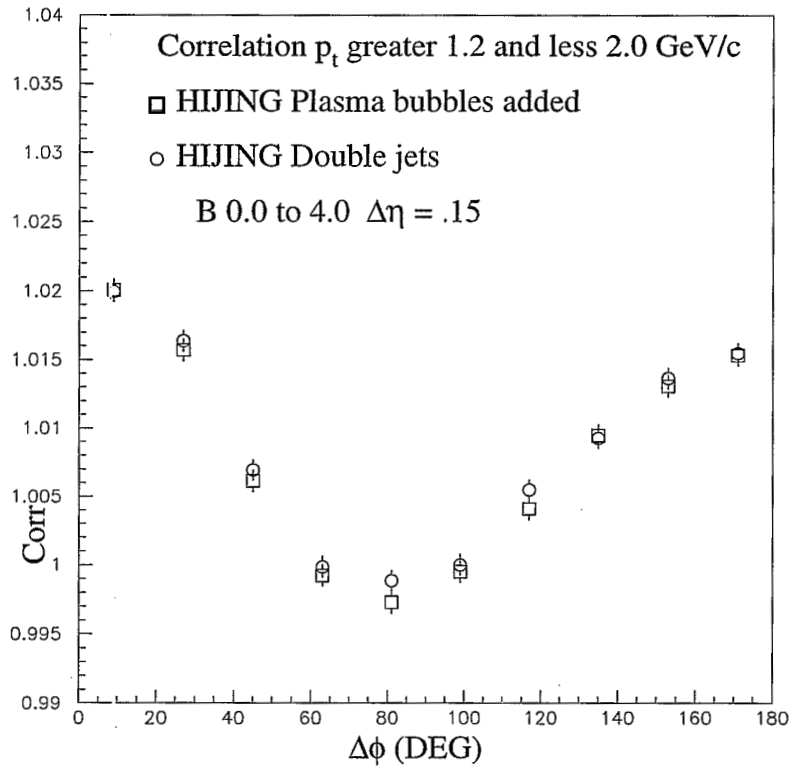


Figure 4: The $\Delta\phi$ correlation of charged particles ($1.2 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) where the difference between the η of the two charged particle is between $0.0 < |\Delta\eta| < 0.3$ for the same models as Fig.[2].

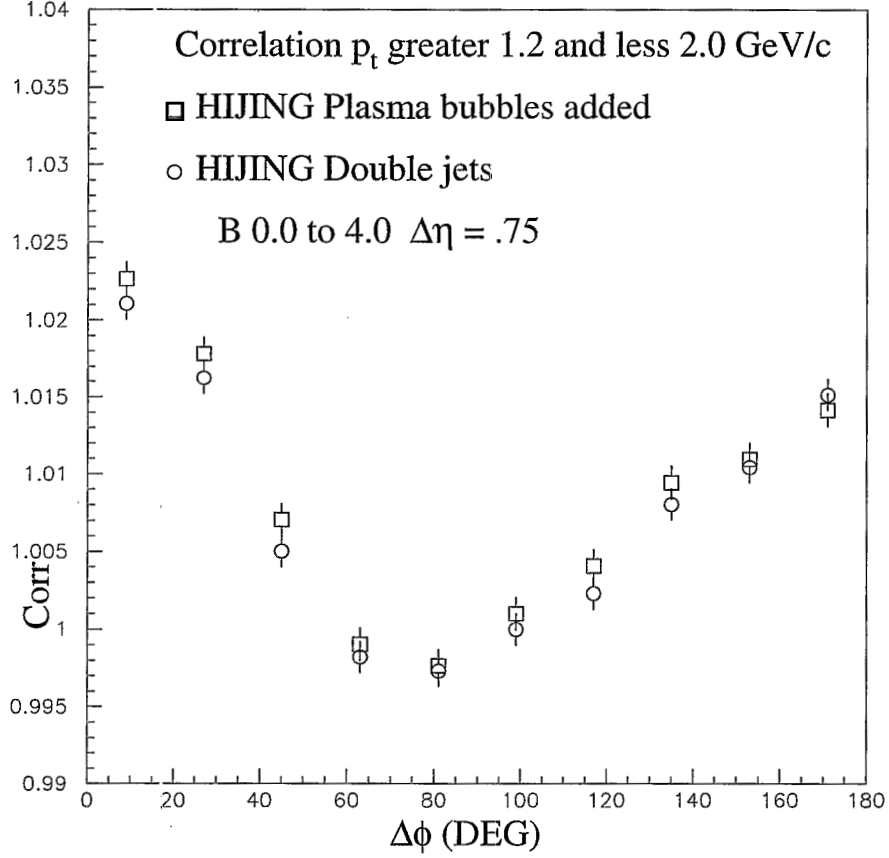


Figure 5: The $\Delta\phi$ correlation of charged particles ($1.2 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) where the difference between the η of the two charged particles is between $0.6 < |\Delta\eta| < 0.9$ for the same models as Fig[2].

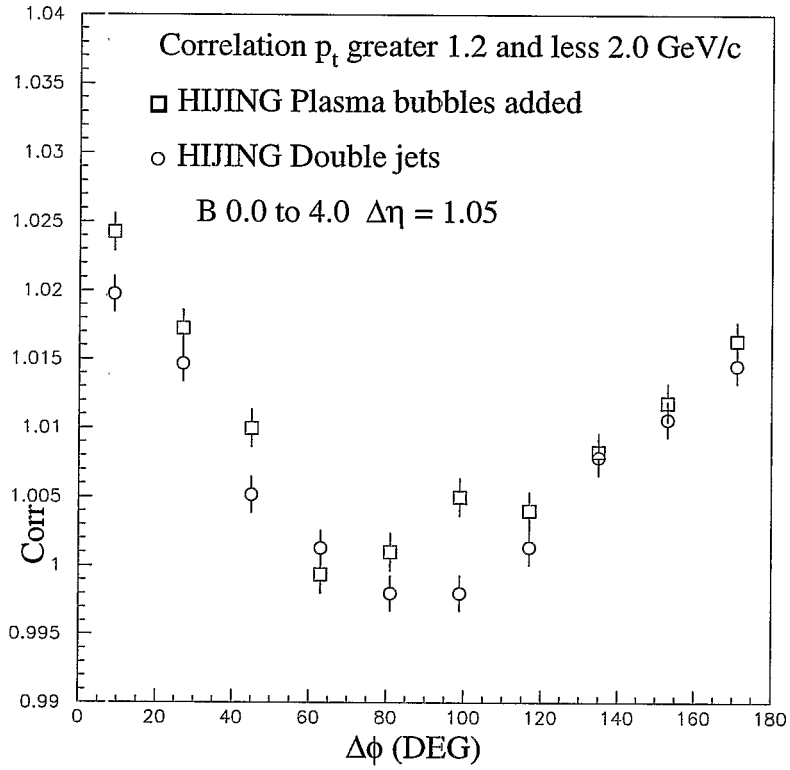


Figure 6: The $\Delta\phi$ correlation of charged particles ($1.2 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) where the difference between the η of the two charged particles is between $0.9 < |\Delta\eta| < 1.2$ for the same models as Fig[2].

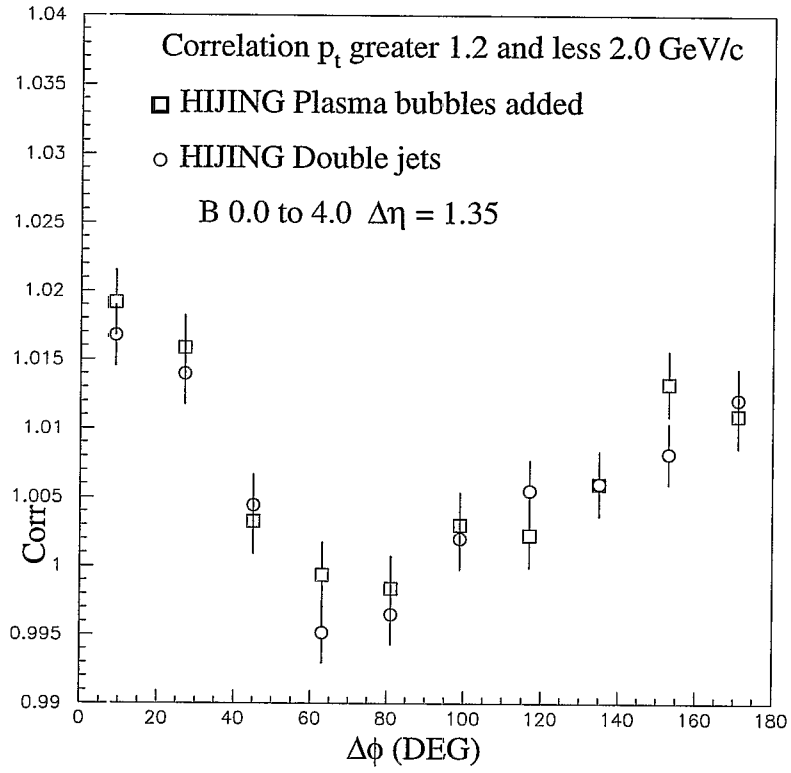


Figure 7: The $\Delta\phi$ correlation of charged particles ($1.2 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) where the difference between the η of the two charged particles is between $1.2 < |\Delta\eta| < 1.5$ for the same models as Fig.[2].

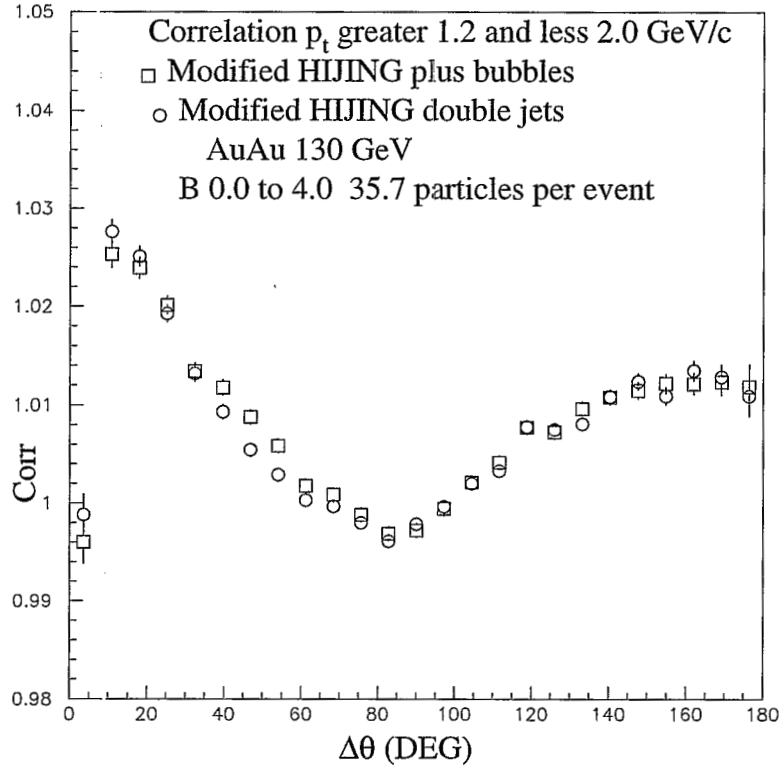


Figure 8: The $\Delta\theta$ correlation of charged particles (where θ is the opening angle and $(1.2 < p_t < 2.0 \text{ GeV/c}, |\eta| < 0.75)$ are cuts) for the same models as Fig.[2].

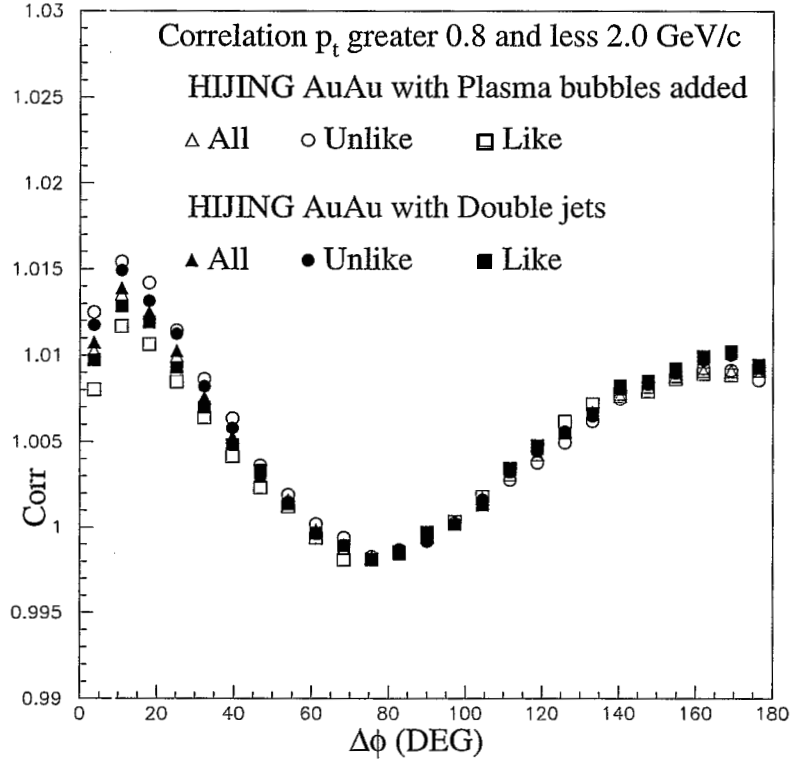


Figure 9: The $\Delta\phi$ correlation of charged particles ($0.8 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) for the same models as Fig.[2]. The open triangles are the same as the squares of Fig. [2] and the solid triangles are the same as the circle of Fig. [2]. The circles are the unlike sign particles and the square are the like sign particles.

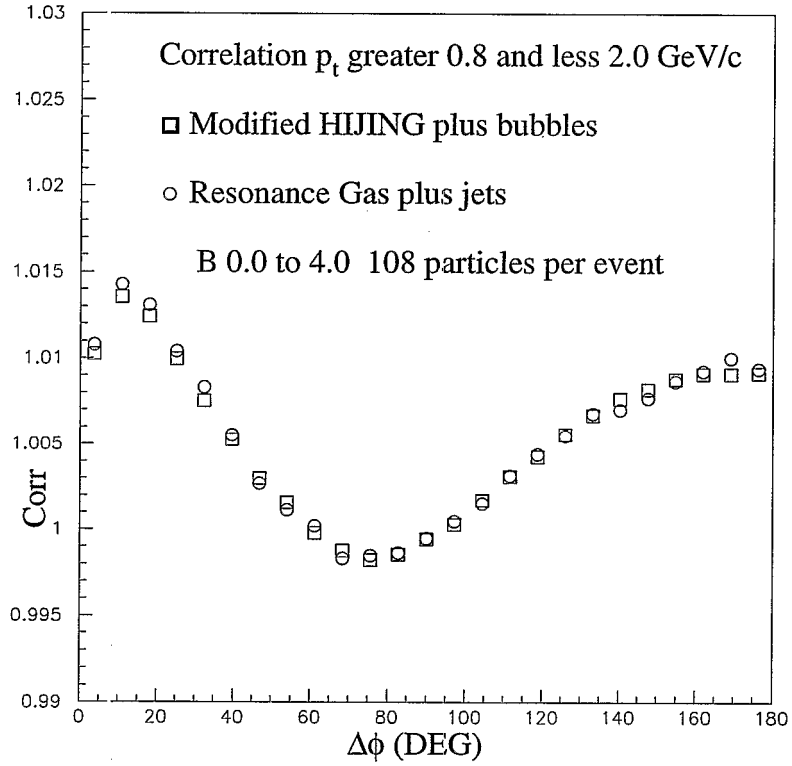


Figure 10: The $\Delta\phi$ correlation of charged particles ($0.8 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) for two different models. One being HIJING plus plasma bubbles square Fig. [2] and the squares here. The second is the circles being a resonance model (see text).

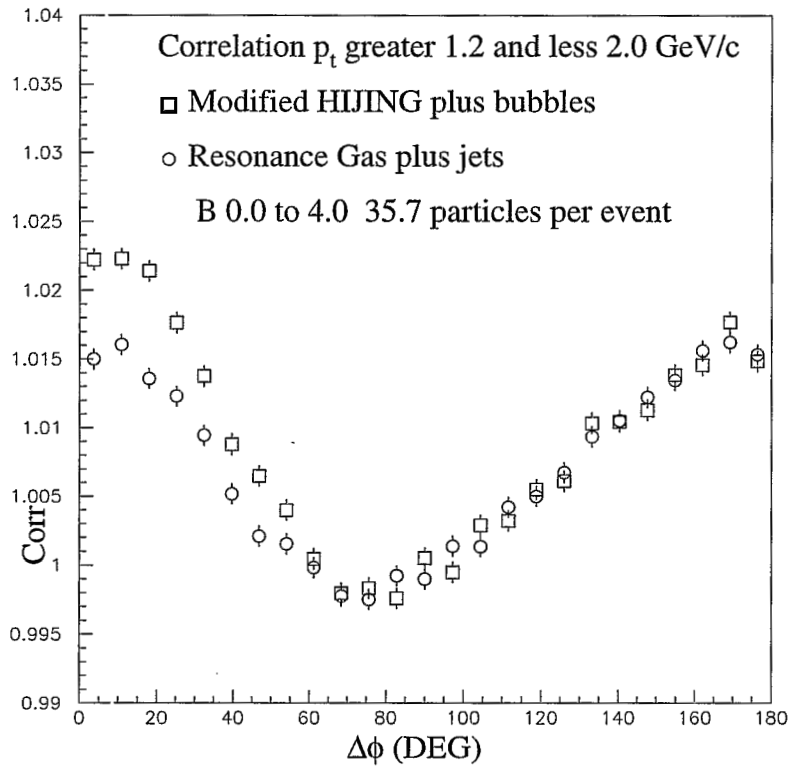


Figure 11: The $\Delta\phi$ correlation of charged particles ($1.2 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$ for the same models as Fig. [10].

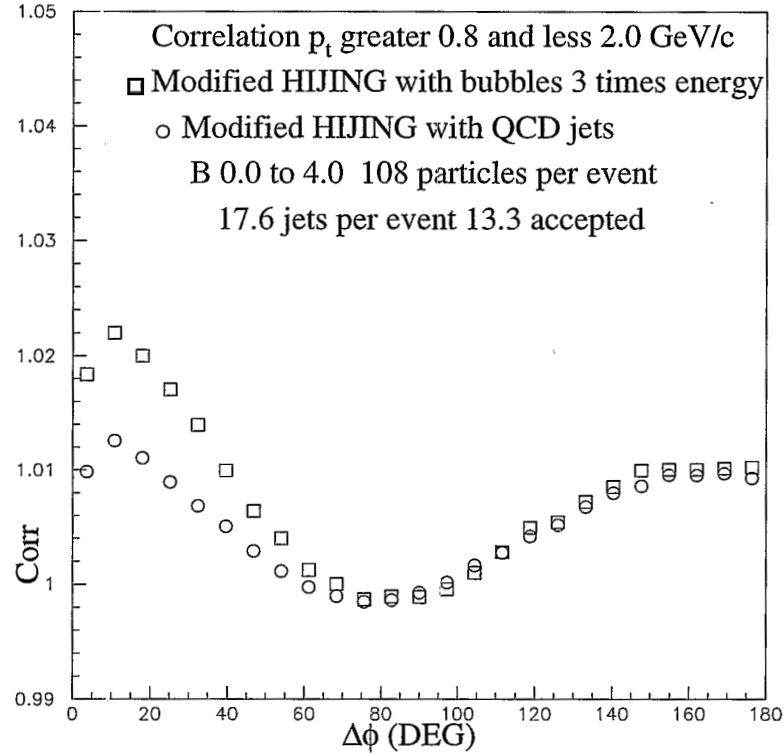


Figure 12: The $\Delta\phi$ correlation of charged particles ($0.8 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) for two different models based on HIJING. The circles are HIJING plus normal number of expected jets and the squares are HIJING plus plasma bubbles which have 3 times the energy of the plasma bubbles used in Fig. [1].

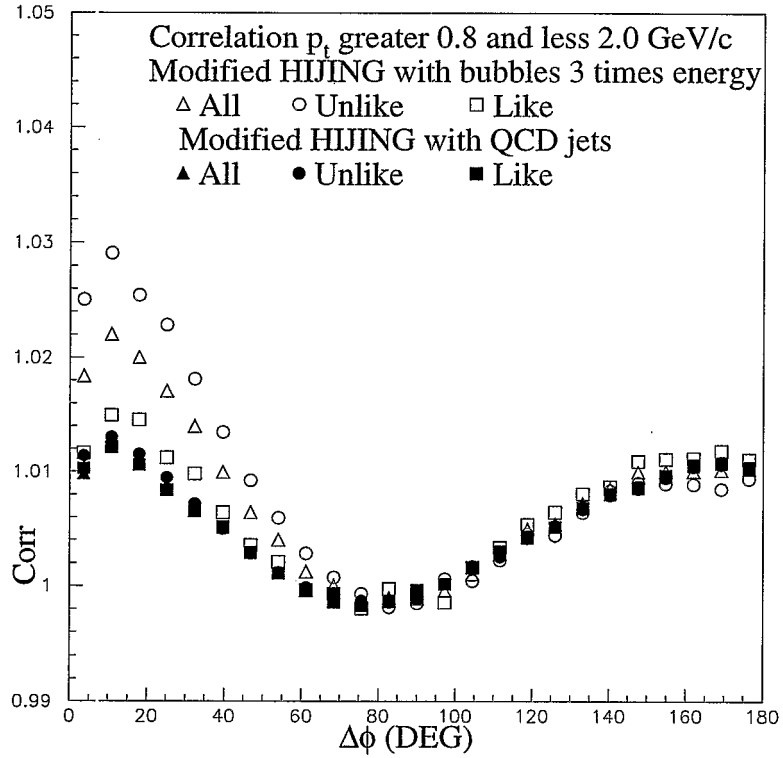


Figure 13: The $\Delta\phi$ correlation of charged particles ($0.8 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) for the same models as Fig. [12]. The open triangles are the same as the squares of Fig. [12] and the solid triangles are the same as the circles of Fig. [12]. The circles are the unlike sign particles and the squares are the like sign particles.

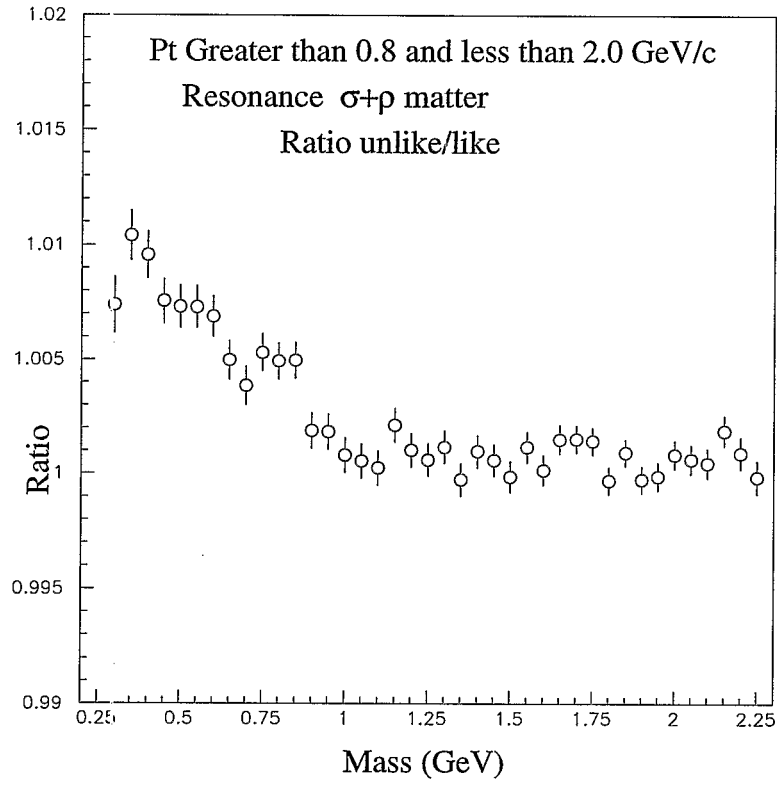


Figure 14: The ratio unlike to like of the effective mass spectrum ($0.8 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) for a pure neutral resonance model (see text).

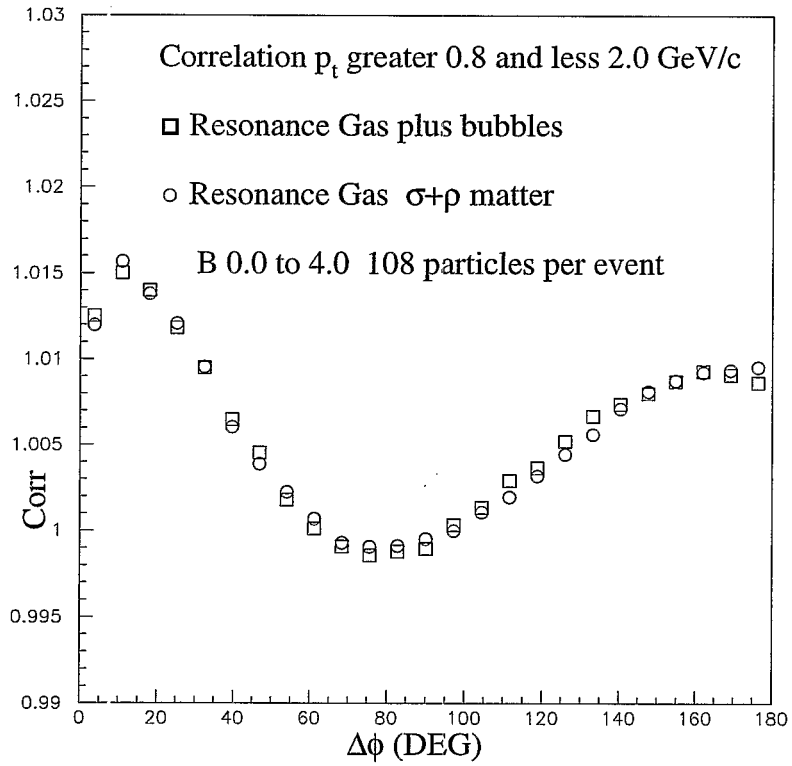


Figure 15: The $\Delta\phi$ correlation of charged particles ($0.8 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) for two different models. One being the resonance gas model plus plasma bubbles the squares and the other being pure neutral resonance of Fig.[14] which is the circles.

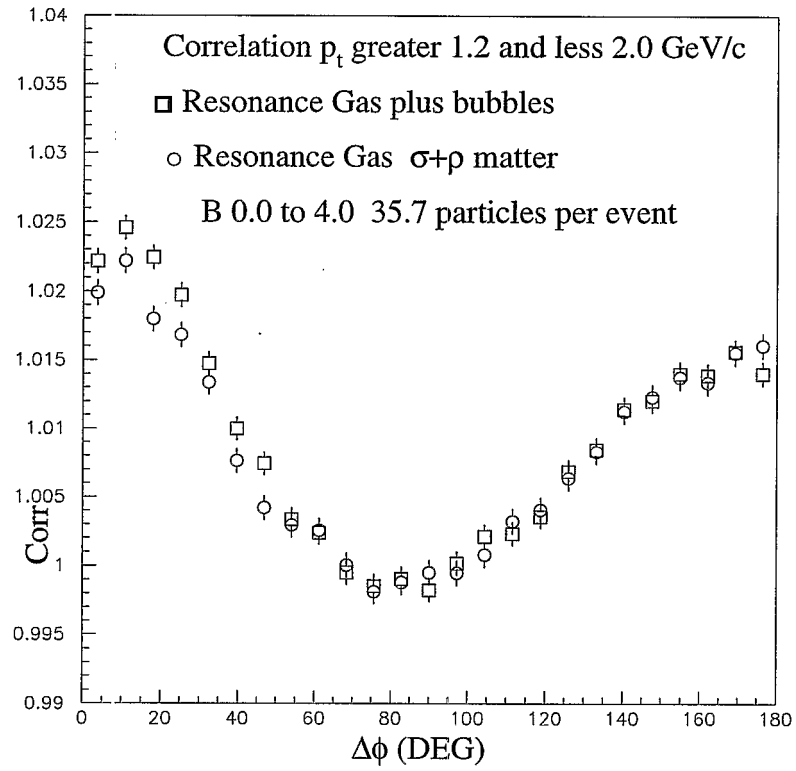


Figure 16: The $\Delta\phi$ correlation of charged particles ($1.2 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$) for the same models as Fig. [15].

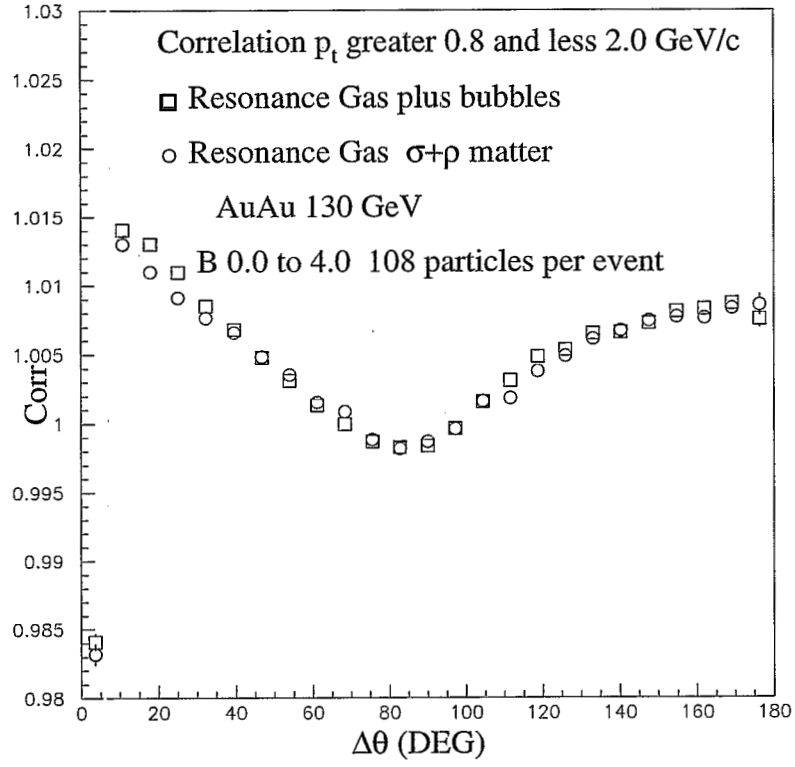


Figure 17: The $\Delta\phi$ correlation of charged particles (where theta is the opening angle and $1.2 < p_t < 2.0$ GeV/c, $|\eta| < 0.75$ are cuts) for the same models as Fig.[15].